Design and Analysis of a Compact Wideband Microstrip Patch Antenna for Ku Band Applications

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ABSTRACT

In this paper, a single layer coaxially fed broadband Rectangular Microstrip Patch Antenna (RMPA) is proposed for Ku (12-18 GHz) band applications. The bandwidth of the proposed antenna is mainly increased by cutting single U slot and further improvement is done by inserting 2 vertical I slots and changing the dielectric constant of substrate material. The dimention of the antenna is 10×5.5 mm^2 with a substrate height of 1.5 mm. The proposed antenna covers exactly 100% of the Ku band with three resonant frequencies at 12.5108 GHz, 14.4204 GHz and 16.4843 GHz. The reflection coefficient or return loss at these frequencies are -35.53 dB, -30.21 dB and -18.96 dB. The VSWR ≤2 for the whole Ku band frequency range. Maximum gain and directivity of the structure is 5.7 dBi and 8.32 dBi respectively. The proposed antenna is suitable for different applications under Ku band satellite operations like Fixed satellite, Mobile satellite, radar etc.

Keywords: Microstrip patch antenna, Wideband, Ku band

1 INTRODUCTION

Antennas are one of the most important and effective components in today's communication system. Microstrip antennas are very popular now-a-days because of their low profile, light weight, low power handling capacity, compatibility with microwave monolithic integrated circuits (MMICs) and optoelectronic integrated circuits (OEICs) technologies [1].

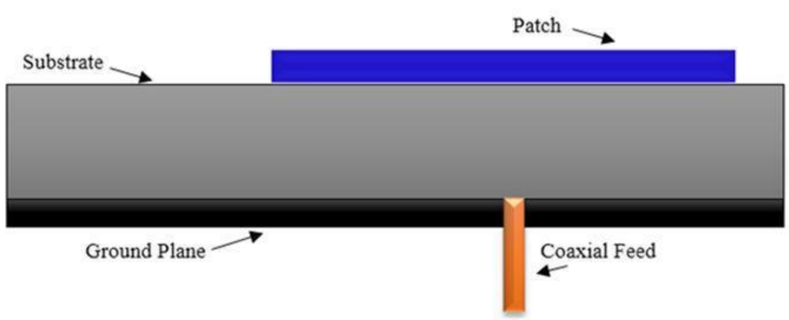


Figure 1: Microstrip Patch Antenna.

A Microstrip patch antenna consists of a radiating patch at the top and a substrate and a ground plane under it as shown in figure 1. The radiating patch is normally made of copper or gold which may be in rectangular, square, circular, triangular, elliptical or in any other regular shape.

Microstrip patch antennas are widely used in civilian and military applications such as satellitecommunications, television, mobile systems, broadcast radio, global positioning system (GPS), vehicle collision avoidance system, radio-frequency identification (RFID), direction finding, radar systems, remote sensing, missile guidance, surveillance systems, and multiple-input multiple-output (MIMO) systems [1]. However there are several drawbacks as well, which makes researcher to examine and investigate further enhancement of Microstrip patch antenna. Generally it shows low bandwidth, low efficiency, low gain, low power handling capacity and so on.

Recently many progresses are already made to overcome above problems. Techniques like increasing the height of the substrate, stacking different antenna elements, cutting slots in patch, the use of low permittivity substrate, electromagnetic band gap structures, and Metamaterials have been proposed to mitigate low bandwidth problem [2]. Shorting pins can be included in patch structure to get broadband characteristics[3]. But, Rectangular shaped U slotted Microstrip patch antenna has become one of the popular in antenna simulation and designing scheme because it can exhibit better wideband [3][4] and multiband characteristics [5].

On the other hand, Antenna technology for satellite application is becoming more and more popular and to cope up with this ever-increasing demand for mobile communication and the emergence of wireless system, antenna design for Ku band application has got its importance. Ku-Band (12-18 GHz) is most commonly used for satellite communications, weather forecasting radars, vehicle tracking, fire detection radars and is used for most VSAT systems on yachts and ships today. Many researches incorporating Ku band has been going on recently [8] [9] [10] with partial coverage of the Ku band.

In this paper, at first a basic RMPA is designed and its characteristics are analyzed. Then a symmetrical U slot is cut in the patch in that RMPA and again its characteristics are analyzed. The comparison of the outcomes of these two different structures shows that introducing a U slot and optimizing various parameters of the patch provides much greater bandwidth than that of basic RMPA. After that the structure of the U slot is changed to further broadening the bandwidth. Finally the substrate material is changed to adjust the frequency range which covers exactly full Ku band.

This paper is organized in four sections. First section presents brief introduction of microstrip patch antenna. Section 2 describes methodology of RMPA and the proposed RMPA. Simulation and results comparison is done in section 3. Section 4 concludes the paper.

2 METHODOLOGY

Primarily a conventional RMPA is designed for 15 GHz by following standard formulas defined for RMPA. The rectangular patch structure is designed over a dielectric substrate Rogers RT5880 having height (h) of 1.5 mm. The length (L), width (W) and other parameters are defined as follows - [9].

$W = \frac{v_0}{2f_r}\sqrt{\frac{1}{\varepsilon_r + 1}}$	(1)

$\varepsilon_{\mathrm{eff}} = \frac{\varepsilon_{\mathrm{r}} + 1}{2} + \frac{\varepsilon_{\mathrm{r}} - 1}{2}\sqrt{\left[1 + \frac{12\mathrm{h}}{\mathrm{W}}\right]}$	(2)

$\triangle L = 0.421h\frac{(\varepsilon_{eff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{W}{h} + 0.8\right)}$	(3)

$L = \frac{v_0}{2f_r\sqrt{\varepsilon_{eff}}} - 2\Delta L$	(4)

ε_r and and ε_{eff} are the dielectric constant and effective dielectric constant of the substrate material and ΔL is the extension of length due to fringing effect. Probe feeding technique is applied to give excitation to RMPA. Following the formulas 1 to 4, the width and the length of the patch are 7.906 mm and 5.697 mm respectively. The optimized width and length is 8 mm and 5.7 mm respectively which is shown in figure 02 below–

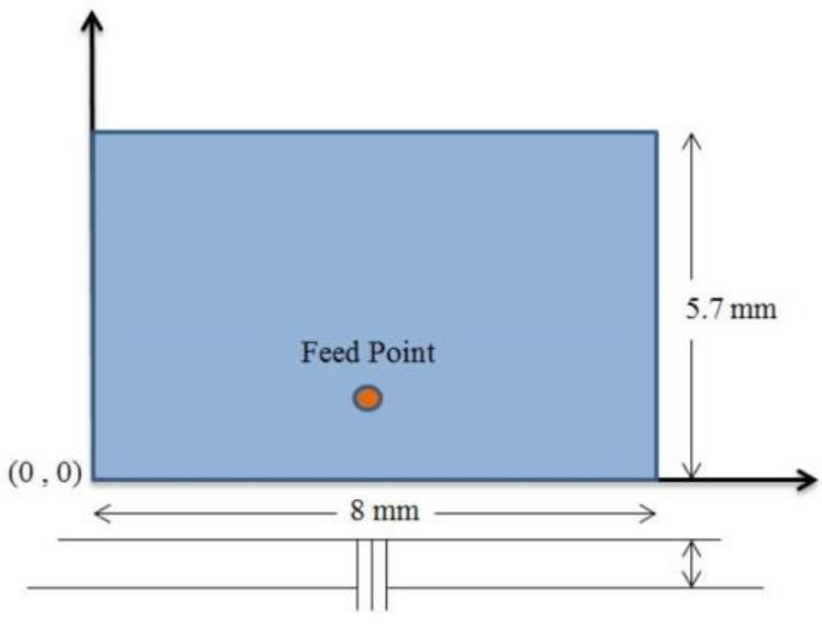


Figure 2: Basic structure of RMPA.

In figure 03 a U slot is cut symmetrically inside the patch structure to widen the bandwidth of the basic RMPA structure. Here three frequencies are used in equations. First frequency is lower frequency which is f_{res2}, second one is central frequency which is f_0 and the third one is upper frequency which is f_{res4}. The equations of dimension of the U slot are as follows [3]:

Height of the substrate, $h \geq 0.06 \frac{\lambda}{\sqrt{\varepsilon_r}}$	(5)

Thickness of the U slot, $E = F = \frac{\lambda\,(air)}{60}$	(6)

Width of the slot, $D = \frac{v_0}{f_{res2}\sqrt{\varepsilon_{eff}}} - 2(L + 2\Delta L - E)$	(7)

Height (C) of the slot, $C \geq 0.3W, \qquad C \geq 0.75D$	(8)

$\varepsilon_{eff}(pp) = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\sqrt{1 + \frac{12h}{D - 2F}}$	(9)

$2\Delta_{B-E-H} = 0.824h\frac{\left(\varepsilon_{eff}(pp) + 0.3\right)\left(\frac{D-2F}{T} + 0.262\right)}{\left(\varepsilon_{eff}(pp) - 0.258\right)\left(\frac{D-2F}{T} + 0.813\right)}$	(10)

Height of the slot from base of the patch, $H \approx B - E + 2\Delta_{\mathrm{B-E-H}} - \frac{1}{\sqrt{\varepsilon_{eff}(pp)}}(\frac{v_0}{f_{res4}} - (2C + D))$	(11)

Using the above equations from 5 to 11, the various dimensions of the RMPA with U slot are calculated and mentioned in the following tables:

TABLE 1. Dimension of the U-slotted microstrip patch antenna

Parameters	**Actual value (mm)**	**Optimized Value (mm)**
Patch Length, L	5.622 mm	5.5 mm
Patch Width, W	10.113 mm	10 mm
substrate Height, h	Minimum 0.81 mm	1.5 mm
Dielectric constant, ε_r	2.2	2.2

TABLE 2. Dimension of the U slot

Parameters	Actual value (mm)	Optimized Value (mm)
U slotThickness, E=F	0.333 mm	0.5 mm
U slotWidth, D	3.6668 mm	3.6 mm
Height of the slot, C	3.033 mm	3.5 mm
Height of slot from base of the patch, H	0.7795 mm	0.75 mm

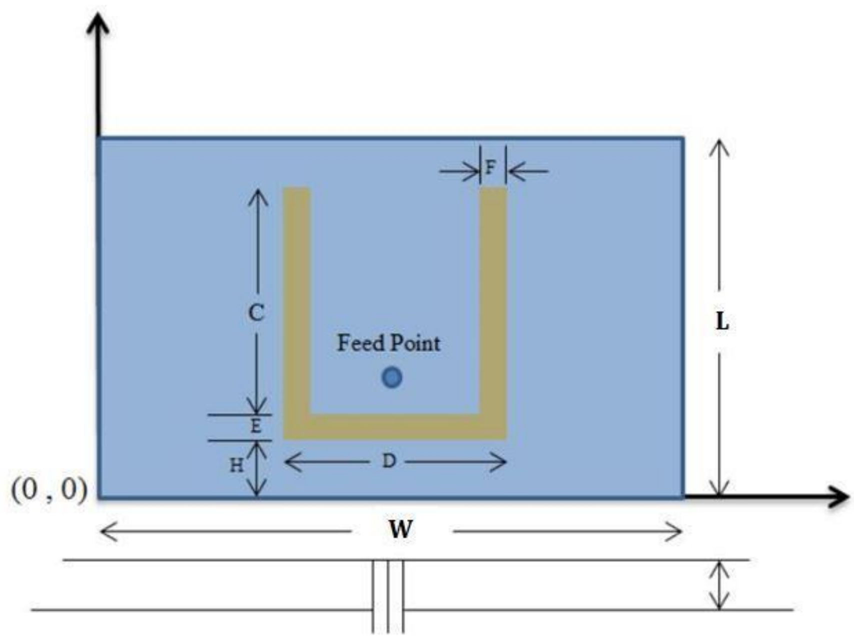


Figure 3: Microstrip Patch Antenna with U slot.

U slot will add second resonance with the first resonance developed by the main microstrip patch antenna. The equation of the frequencies can be derived by the surface current distribution of the antenna.

Figure 4(a) and 4(b) shows the surface current path length for the two resonant frequencies [10]. In 4(a) and 4(b) average surface current path is [10]–

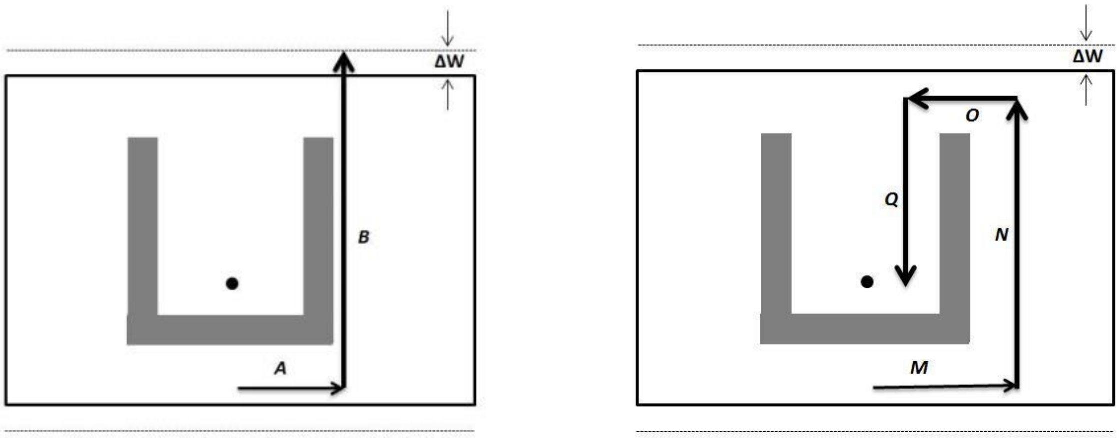
$$\frac{\lambda_1}{2} = A + B = \left({}^{D}/_{2}\right) + W + \left({}^{3}/_{2}\right)\Delta W - {}^{H}/_{2} \quad (12)$$

$$\lambda_2 = {}^{L}/_{2} + W + \left({}^{3}/_{2}\right)\Delta W - \left({}^{D}/_{4}\right) + F - H - {}^{H}/_{2} + {}^{F}/_{2} \quad (13)$$

Here, ΔW is also due to the fringing field effect. Two resonant frequencies can be expressed by the following two equations [10]-

$f_1 = \dfrac{c}{2\lambda_1\sqrt{\varepsilon_{eff}}}$	(14)

$f_2 = \dfrac{c}{\lambda_2\sqrt{\varepsilon_{eff}}}$	(15)



(a) (b)

Figure 4: (a) Average surface current path for frequency f_1. (b) Average surface current path for frequency f_2.

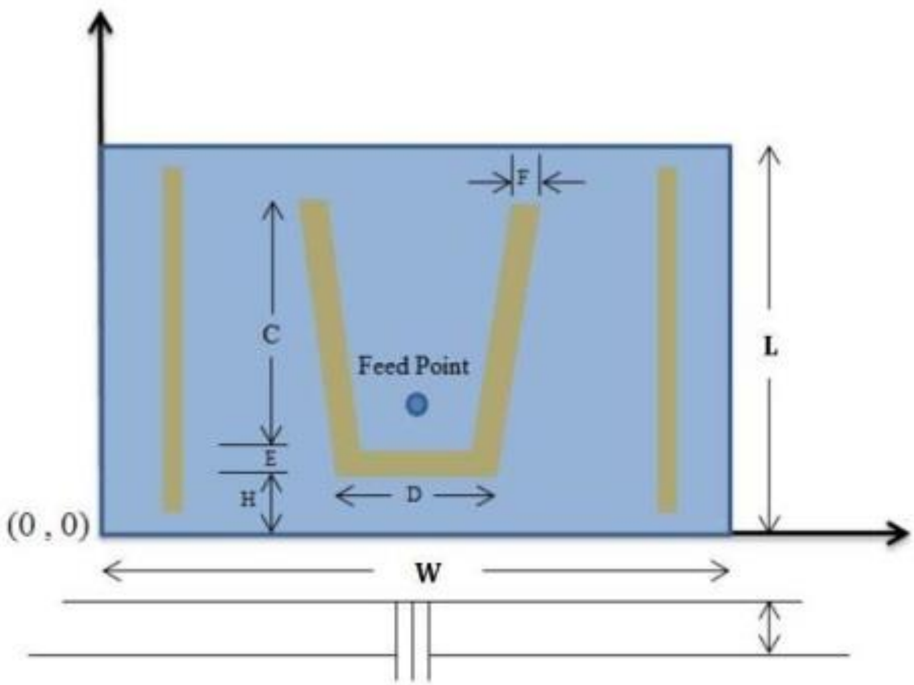


Figure 5: MPA with U & Vertical slots

To increase the bandwidth of the RMPA the width of the slot, D is decreased gradually from both sides and two vertical slots are inserted inside the patch to get third resonant frequency. Figure 05 shows the modified U-slotted patch antenna with two vertical slots.

3 SIMULATION AND RESULT

Dimention of all structures are designed at 15 GHz resonant frequency. After simulation RMPA (figure 01) shows a bandwidth from 14.692 GHz to 16.0143 GHz (1.3223 GHz Bandwidth) at resonant frequency at 15.3276 GHz. After adding a U slot inside the patch, with optimized dimensions the bandwidth of the proposed structure increases by 307.97% (5.3947 GHz Bandwidth) which resonates at13.22 GHz and 16.4343 GHz. The calculated value of f_1 and f_2 from equations 17 to 20are so close to the simulation result which are shown in table 3.

TABLE 3: Comparison of calculated and measued value of resonant frequencies

	Calculated by eqs. 17-20	Measured
f_1 (GHz)	13.33	13.22
f_2 (GHz)	16.70	16.43

TABLE 4. RMPA vs RMPA with U Slot

Antenna parameters	RMPA	RMPA with optimized U slot	RMPA with modified U slot	
Resonant frequency (GHz)	15.3276	16.4343	13.5184	17.3375
Return loss (dB)	-12.1369	-33.0043	-32.6425	-22.031
Bandwidth (GHz)	1.3223	5.3947	1.8093	3.8191
Gain (dBi)	5.22872	5.18648	6.18975	4.40381
Directivity (dBi)	8.03626	8.51307	7.9948	8.70958

TABLE 5. RMPA with modified U and two vertical slots

Antenna parameters	RMPA with modified U and two vertical slots (ε_r = 2.2)		
Resonant frequency (GHz)	13.3697	15.4752	17.4847
Return loss (dB)	-35.1328	-31.5519	-24.5437
Bandwidth (GHz)	6.238 (12.8509 GHz – 19.0889 GHz)		
Gain (dBi)	6.25238	1.34475	5.4693
Directivity (dBi)	7.96739	7.07293	8.60285

With modified U slot (without two vertical slots) the antenna bandwidth increases significantly, but for higher values of modification a small portion of the graph goes up of the -10dB level which is dual band characteristics. Addition of two vertical slots in the patch generates another resonance and the structure works as a single band antenna enhancing the bandwidth. Table 4 and 5 shows comparison between the parameters of different structures.

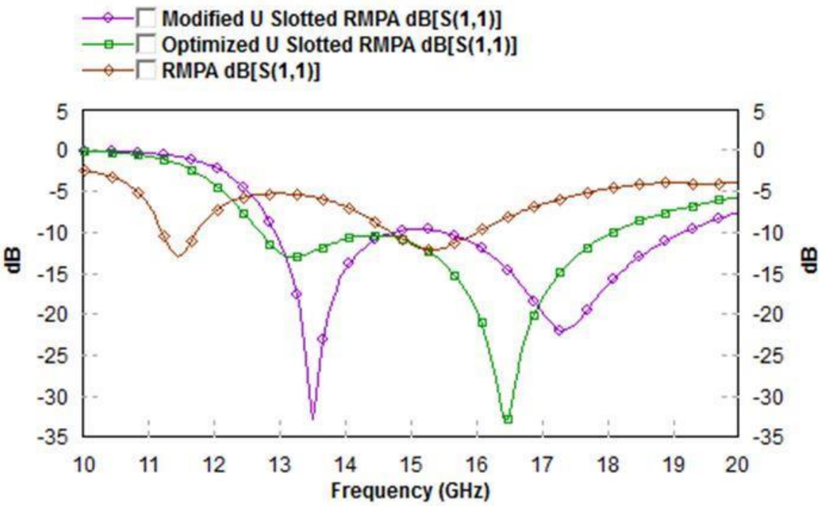


Figure 6: Reflection coefficient of RMPA, MPA without and with modified U slot

Figure 06 shows the comparison between reflection coefficient of RMPA and RMPA with optimized and then modified U slot. It is clear from the graph that the bandwidth is increased with the optimization of U slot. After the modification of the U slot its bandwidth increased further, but it shows dual band.

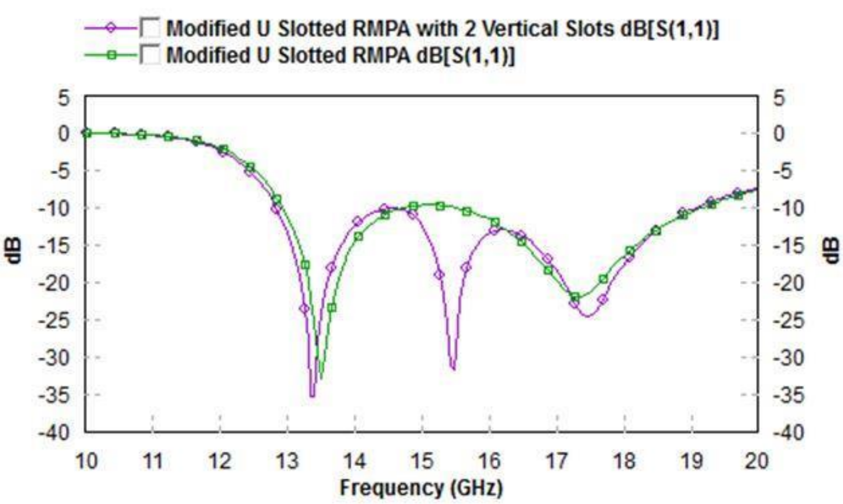


Figure 7: Reflection coefficient of RMPA with modified U slot & RMPA with modified U slot and 2 vertical slots.

To make it single band antenna, two vertical I slots are inserted inside the patch which creates another resonant frequency at 15.4752 GHz. And the antenna operates under a large frequcncy band from 12.85GHz to 19.09 GHz (figure 7).

For tuning the bandwidth from 12GHz to 18GHz to cover whole Ku-band the substrate material is changed (dielectric constant is increased). Table 6 shows the changes in bandwidth for different substrate material.

TABLE 6: Shifting of Bandwidth with different Substrate material

Substrate Material	Dielectric Constant	Bandwidth (GHz)
Rogers RT5880(lossy)	2.2	6.1568 (12.84-18.99)
Rogers RT5870 (Lossy)	2.33	6.1673 (12.56-18.73)
Rogers Ultralam (Lossy)	2.5	6.1441 (12.21-18.35)
Taconic TLT-7 (lossy)	2.6	6 (12.0-18.0)

With the increase in dielectric constant the total bandwidth shifts to left. For Taconic TLT-7 (lossy) the antenna covers full Ku-band (12GHz-18GHz) with three peaks at 12.5108 GHz, 14.4204 GHz and 16.4843 GHz. The maximum return loss, gain and directivity of this proposed antenna are -35.53 dB, 5.7 dBi and 8.32 dBi.

Figure 8 depicts the shifting of bandwidth from left to right with the change in dielectric constant. Figure 9 shows the voltage standing wave ratio (VSWR) of the poroposed antenna.

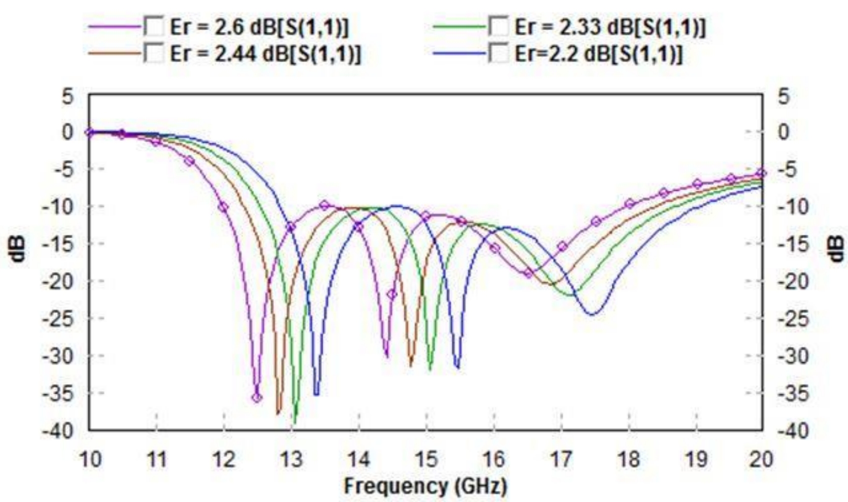


Figure 8: Reflection coefficient of proposed antenna for various substrate material.

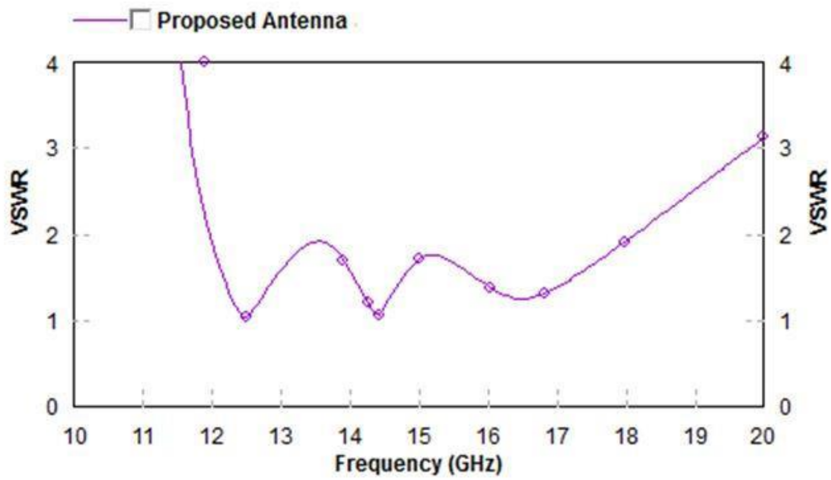


Figure 9: VSWR of the proposed antenna

Figure 10, 11 and 12 shows the Two-dimensional radiation patterns at the three resonances of the proposed antenna respectively.

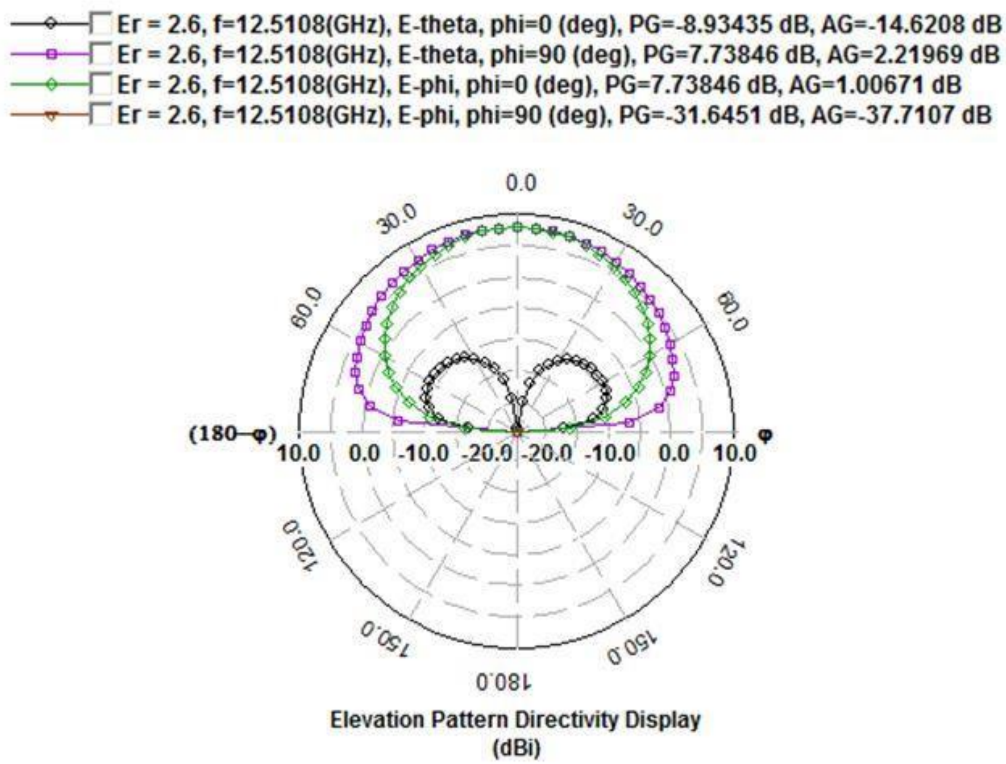


Figure 10: Two-dimensional radiation pattern at 12.5108 GHz

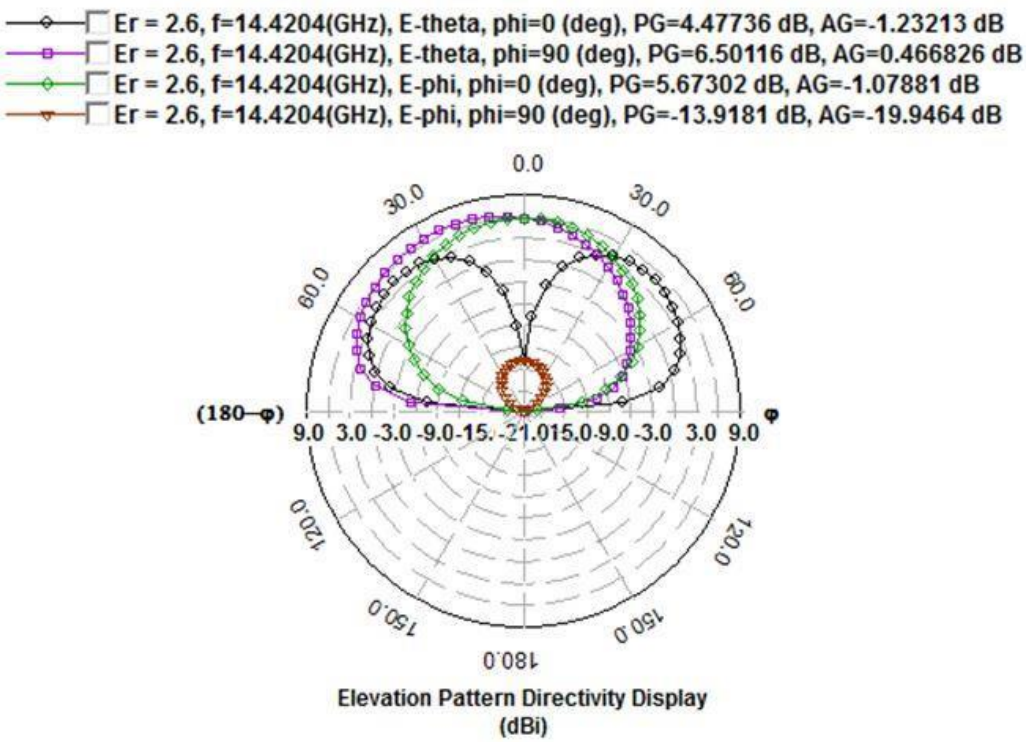


Figure 11: Two-dimensional radiation pattern at 14.4204 GHz

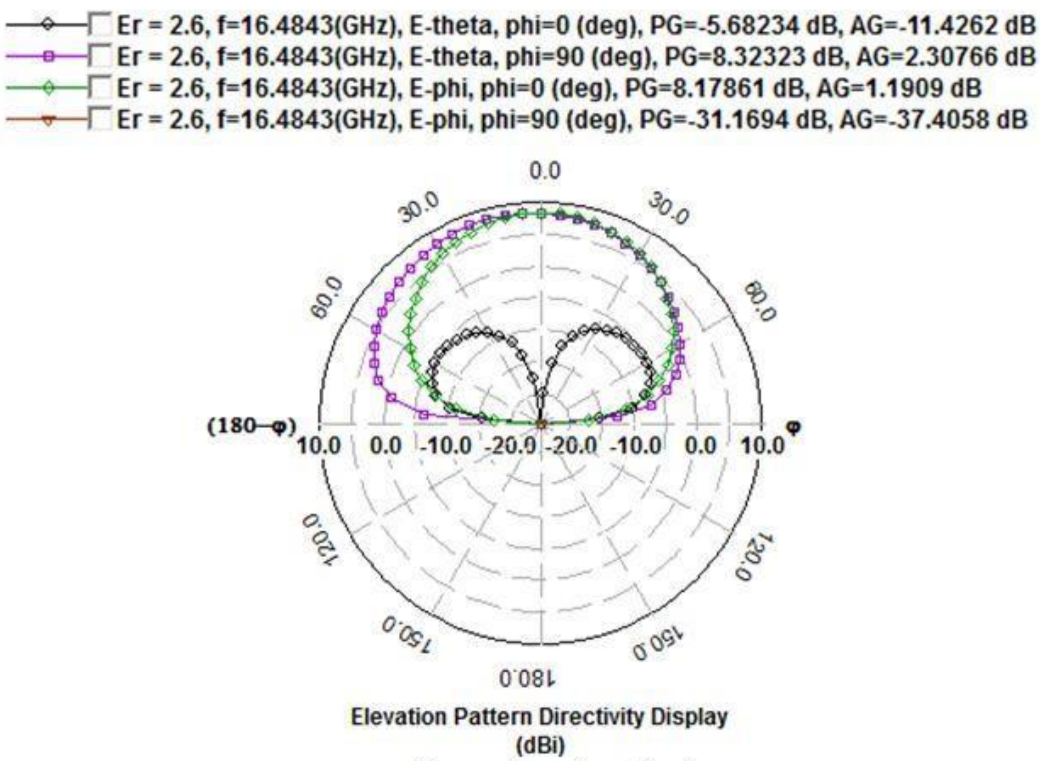


Figure 12: Two-dimensional radiation patternat 16.4843 GHz

4 CONCLUSION

A compact Microstrip Patch Antenna with modified U slot and two vertical slots has been proposed in this paper to cover full Ku band. The proposed antenna is suitable for all satellite or other applications under Ku band having 6 GHz bandwidth which overcomes the problem of low bandwidth characteristics of microstrip patch antenna. This paper also clearly shows that a basic RMPA exhibits high bandwidth when a U slot is inserted in the patch. The value of Gain and directivity of the proposed antenna is also in acceptable limit. Further modification can be done to get multiband characteristics or to enhance the gain and directivity of the proposed antenna.

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